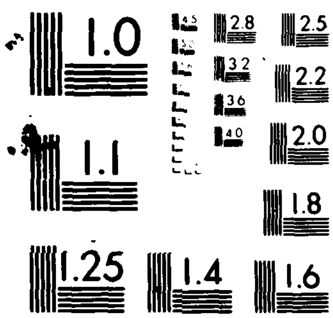

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RESERVOIR STORAGE DETERMINATION BY COMPUTER SIMULATION OF FLOOD CONTROL AND CONSERVATION SYSTEMS

by

BILL S. EICHERT

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The paper presents ways that a comprehensive simulation computer program (HEC-5) can be used in planning a water resources system composed primarily of multipurpose reservoirs with flood control as a major project purpose. In addition, techniques for determining reservoir storage requirements for flood control, water supply and hydropower are presented.

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RESERVOIR STORAGE DETERMINATION BY COMPUTER [1]
SIMULATION OF FLOOD CONTROL AND CONSERVATION SYSTEMS

by Bill S. Eichert[2]

INTRODUCTION

This paper presents ways that a comprehensive simulation computer program can be used in planning a water resources system composed primarily of multipurpose reservoirs with flood control as a major project purpose. The computer program HEC-5, Simulation of Flood Control and Conservation Systems, will be used to illustrate the ways in which a generalized computer program can be applied to a wide variety of reservoir systems. The HEC-5 model can be used in almost any reservoir system regardless of location, project purposes, and physical conditions in the basin by specifying as input data such items as the configuration of the reservoirs in the basin, the project purposes, streamflow data, channel routing criteria, evaporation data, etc.

OVERVIEW OF SIMULATION MODEL

The model HEC-5 as described in the users manual (reference 1), is a simulation model that can simulate the operation of a system of reservoirs for both flood control and conservation purposes. The operation for flood control is based on evacuating the seasonal flood control space in each

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[1] Presented at International Symposium on Specific Aspects of Hydrological Computation for Water Projects, Leningrad, USSR, September 1979.

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reservoir as soon as possible without causing flooding at specified downstream locations. This type of operation is possible of course only if the flood control outlets are gated. Where a choice exists about which reservoir should release the most water, the decision is made based on balancing the storage within the reservoirs among themselves according to a prespecified set of storage levels input to the model. The release decisions are complex because of the streamflow routing effects which cause the releases for a given time period to be spread out over many future periods.

The conservation operation is based upon releasing water to supply all specified requirements for flow (and energy for hydropower sites) at all locations in the basin without wasting any water. Where a choice exists about which reservoir should be drawn down the most, the decision is based on balancing the storage within the reservoirs among themselves using the same set of storage levels as in the flood control operation.

The program has the capability of using any computational time interval from one hour to one month for a given flood or time sequence. It also has the ability to combine time sequences that have different computational time intervals so that monthly computations can be performed during non-flood periods and short interval routings (daily or multi-hourly) can be used during flood periods.

While the program is primarily a hydrologic simulation tool, it also has economic evaluation capabilities for determining flood control and hydropower benefits (see references 2 and 3). Economic evaluation capabilities for flood control include flood damage, flood damage reduction, benefit-costs ratios, and net benefits. The benefits for operating for hydropower are based on input unit prices for primary and secondary energy plus a penalty for shortages in primary energy. Other conservation benefit evaluation capabilities are planned for future additions.

Selection of the best location and size of each project must be accomplished by using the model to simulate alternative systems separately based on a structured strategy formulation (reference 6), knowledge of the system and objectives, public input, and plain sound judgment which is required to reduce the number of such alternative systems to a reasonable number. The use of operation research techniques has, thus far, not proven to be

widely useful because of the complexities of water resources systems and noncommensurate objectives in water resource management.

CRITERIA FOR STORAGE SELECTION

The determination of the amount of reservoir storage for a specified purpose such as flood control is based on hydrologic analyses that are governed by project formulation criteria. While project formulation criteria are beyond the scope of this paper, the guiding formulation principles in most free enterprise countries are generally that the project, with the specified amount of storage, must be economically justified (benefit/cost ratio must exceed one), the project should be formulated to the extent practical to maximize net economic benefits, and the project should not result in significantly increased flood hazards for any flood event, especially one that would exceed the design capacity of the reservoir system (see reference 4). Projects with conservation storage should also provide a reasonable guarantee (probability) of dependable water supply from the reservoirs.

The usual procedure for determining the location and size of the projects in a system is based on selecting and analyzing projects (including economic and environmental analyses) of various sizes and locations which will provide different degrees of protection for flood control and different amounts of firm energy and yields for hydropower and water supply, respectively. Determination of system or project flood control storage is usually done separately from the conservation storage determination.

FLOOD CONTROL STORAGES

Flood control studies are usually initiated by determining reservoir sites for several alternative systems that can provide a reasonable level of protection (in many instances full protection against the largest historical flood is initially assumed) to the communities affected by extensive flood damages. The better systems, and thus the selected reservoir sites, can be determined by using a computer program such as HEC-5 that will

simulate the detailed hydrologic operation of each system and provide the estimated flood damages with and without the system in place (see references 5 and 6). The system is usually operated for all major historical floods, and then an estimate of the basin-wide expected annual flood damages (EAD) is computed. Where study funds are limited, a few historical and/or synthetic floods (and ratios of those floods to reflect a broad range of flood event magnitudes) can be used to estimate the EAD. Once the best system is obtained, each project can then be easily deleted in turn from the model to determine if each reservoir is justified on a "last added" basis. One data model for the HEC-5 program can be constructed for all the above studies if all the potential sites are included initially. The specific system to be evaluated can then be specified by a single card which specified which reservoirs are to be deleted from the system.

The initial amount of flood control storage in each selected site is usually tested by selecting and evaluating several acceptable alternative levels of protection and by evaluating the benefits and costs of the system for each. The size is then based on the principle of maximizing net benefits as long as an acceptable degree of protection is provided and that social and environmental concerns are acceptably addressed or compensated.

WATER SUPPLY STORAGE

An additional criterion used in the selection of reservoir water supply storage is that the supply must be reasonably dependable. In the United States, the criterion for dependable is usually that the project must be able to provide the stated dependable yield through a recurrence of the most severe critical drought of record. Very few projects in the United States have been designed using stochastic flows instead of historical flows. The limited use of models to generate synthetic flows even for monthly periods (see reference 7) is due in large part to deficiencies in the models for reproducing droughts in many locations as severe as some recorded droughts. Most water supply studies are for single reservoirs operating to satisfy seasonal requirements for water at the dam and at a nearby downstream location, although many system studies for irrigation and water supply have been conducted.

The HEC-5 model can be used to determine the reservoir storage requirements for various conservation purposes using the same basic data model as constructed for flood control purposes. Additional data will have to be added to the model, such as evaporation rates and flow requirements for conservation purposes. The flow data cards for non-flood events will be substituted for or added to the flood flow data cards.

Most conservation studies initially ignore flood control operations, and use monthly flows for the period of record. Thus the conservation studies are conducted to determine how much reservoir storage is required to supply the estimated demands on the system. If the demands exceed the available yield then the project is sized to produce the maximum yield that will meet the required economic, social, and environmental concerns while still maintaining a reasonable drawdown period (not to exceed 7-10 years).

For determining reservoir sites and amounts of storage in meeting system demands, the program is used in an iterative fashion, similar to the flood control situation. Several alternative reservoir systems are selected along with the conservation storage to be used in each reservoir. Several simulation runs of the program are then made for each alternative system to determine the minimum amount of storage required to supply all conservation requirements including hydropower. The selection of the best system is then based on non-hydrologic criteria, since each of the feasible alternative solutions has been developed to provide the specified yields with an acceptable degree of reliability.

Prior to the start of the system runs, it may be useful to use the program on each reservoir individually in order to determine how much conservation storage would be required to provide certain fixed demands on the project or conversely to determine the yields that can be expected from a certain amount of conservation storage. The HEC-5 program does have routines in it to automatically determine the maximum yields given the storage, or the storage based on fixed yields. The yields can include seasonally varying water supply demands at or below the reservoir and seasonal hydropower energy demands. The optimized storage can also vary seasonally.

HYDROPOWER STORAGE

Storage requirements for hydropower projects are determined in a similar manner to other conservation purposes. Use of the HEC-5 program can be made for single projects as well as for systems of reservoirs.

The determination of the storage requirement for a single reservoir can be automatically made with the model based on supplying a prescribed seasonal energy demand schedule for the reservoir. The firm annual energy from a fixed amount of storage can also be determined automatically by the program.

System energy requirements can be supplied for a reservoir system which includes several power reservoirs. These requirements are met in addition to the normally reduced individual project energy requirements by drafting water from the power projects to keep them in balance with each other as prescribed by user input target storage levels. The system energy requirements are developed, for that part of the regional energy load that is to be provided by hydropower projects, using a series of simulations of the system by the HEC-5 model. The system hydropower energy requirements are normally changed by the user until the power system storage is exhausted during the most critical period of historical streamflow.

Pumped storage projects can be simulated by the model with or without other reservoirs. One recent simulation was for a system of three power reservoirs in series operating as a system with the middle reservoir having reversible turbines. The operation of this system was made on a daily basis for the period of record (about 20 years) and an hourly operation was made for several selected weekly periods (see reference 8).

RULE CURVE OPERATION

The use of seasonal rule curves to allow the use of flood control storage for conservation purposes during certain seasons when the need for flood control is reduced is very beneficial in certain geographical locations. The computer model HEC-5 can be used to develop these rule curves, but each attempt to improve the rule curves requires a new system simulation of the hydrologic and economic consequences of that change.

MULTIPURPOSE OPERATION

Once the reservoir sites are established and the approximate conservation storage determined on a monthly basis, the same data model can be used to simulate the operation for both flood control and conservation purposes. A single time step may be selected for the routing, such as using daily flows for the period of streamflow record or a combination of flow time sequences can be used such as using monthly flows during the non-flood periods and daily or multihourly routing during the flood period. The long multipurpose routing can be useful for firming up project storages and for providing useful information on duration and frequency of various hydrologic variables such as flows, reservoir storages, energy production, etc.

CONCLUSIONS

The use of a computer model such as HEC-5 allows the detailed simulation of the hydrologic and economic consequences of a system of reservoirs and is a major improvement over previous techniques that required detailed sequential routings by hand methods. Nevertheless, the general problem of sizing and siting multipurpose reservoir system is so complex and each application has so many combinations of potential solutions that it is impossible to ever get the optimum system. The determination of a near optimum solution is still greatly dependent upon the ability of the engineer to organize and follow a systematic approach in developing alternative system configurations and performance criteria that can be used to satisfy water management needs. The future role that operation research techniques can play in screening these potential solutions into a manageable number of alternatives is still very much in doubt. With the strong current public sentiment in many countries against designing and constructing reservoir systems, the future for major progress in this area seems bleak.

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